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BIOLOGICAL NUTRIENT REMOVAL FROM MUNICIPAL WASTEWATER OF MOSUL CITY

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ABSTRACT

Nitrogen and phosphorus are essential to the growth of microorganism, plants, and animals, so that, they are known as major nutrients. The removal of nutrient before discharging treated wastewater is desirable not only to prevent eutrophication, but for reuse purposes. In Iraq, Due to the insufficient water supplies in recent years, the wastewater Authority's initiate a new program aiming at upgrading existing treatment facility in order to achieve the nutrient removal for reuse applications.Anactivated sludge A2O process was developed in a Laboratory- bench scale plant to evaluate the influence of operating conditions on the Biological Nutrient Removal for the domestic wastewater of Mosul city. According to results obtained, the alkalinity content in the raw waste water under study is adequate to maintain the process of biological nutrient removal. The results revealed that at high percentages of return activated sludge recirculation ratio (RAS), the biological phosphorous removal is less efficient. The total nitrogen removal is slightly affected by RAS ratio. In order to meet Iraqi standard with respect to nutrient (N, P), organic (COD) and solid (TSS) contents , employing A2O scheme, The optimum internal cycle ratio IR obtained from the study is(200%), While the significant range of Returned activated sludge recirculation ratio (RAS) is located within the range 20-40%.

KEYWORDS: Biological Nutrient Removal, A2O, Internal Cycle, Recirculation Ratio

INTRODUCTION

Nitrogen and phosphorus are essential to the growth of microorganism, plants, and animals, so that, they are known as major nutrients. They are the primary causes of eutrophicationwithin surface waters. The negative sign of eutrophication is represented by low dissolved oxygen, fish kills, and depletion of desirable flora and fauna. Excessive amounts of these nutrients can also stimulate the activity of microbes, such as which can be potentially harmful to human health. Hence, The removal of nutrient before discharging treated wastewater is desirable not only to prevent eutrophication, but for reuse purposes.

Nutrient removal processes include physical treatment (sedimentation and filtration) for particulates, and chemical or biological treatment for dissolved nutrients. Biological Nutrient Removal removes total nitrogen (TN) and total phosphorus (TP) through the use of microorganisms under different environmental conditions within the treatment process.

There are a number of biological nutrient removal treatment process configurations available.Although the exact configurations of each system differ, biological nutrient removal systems designed to treat Total Nitrogen must have an aerobic zone for nitrification and an anaerobic zone for de-nitrification, while biological nutrient removal systems designed to treat Total Phosphorus must have an anaerobic zone free of dissolved oxygen and nitrate.

In Iraq, Due to the insufficient water supplies in recent years, the wastewater Authorities'

Initiate a new program aiming at upgrading existing treatment facility in order to achieve the nutrient removal for reuse applications.

THEORY OF BIOLOGICAL NUTRIENT REMOVAL

Biological Nitrogen Removal (BNR)

The biological processes that primarily remove nitrogen are nitrification and denitrification.

Nitrification is defined as a two-stage biological process, which occurs under aerobic conditions (in the presence of oxygen). During nitrification, ammonia is oxidized to nitrite by one group of autotrophic bacteria, known as Nitrosomonas. The nitrite is then further oxidized to nitrate by another group of autotrophic bacteria, known as Nitrobacter. Typical aerobic biological activated sludge existing at wastewater treatment plants can be modified to achieve nitrification by extending the mean cell residence time beyond the values used for typical activated sludge processes while maintaining adequate dissolved oxygen Thus, Nitrification can be accomplished simultaneously with BOD removal processes if the mean cell residence time is extended from 6 to 8 days, thereby being very close to the optimum value for CBOD (carbonaceous BOD) removal.

De-nitrification occurs under anaerobic conditions (in the absence of oxygen), and involves the biological reduction of nitrate to nitric oxide, nitrous oxide, and nitrogen gas which is released to the atmosphere. De-nitrification can be accomplished by heterotrophic bacteria in the absence of dissolved oxygen. These bacteria use the oxygen in the nitrate, instead of dissolved oxygen, to digest organic material, thereby releasing nitrogen gas as a waste by-product.

For treatment facilities to achieve optimum biological nitrogen removal it is important to process wastewater through a series of aerobic and anaerobic stages, to ensure complete nitrification and de-nitrification is achieved.

Biological Phosphorus Removal (BPR)

Biological phosphorus removal involves a physical process that results in the growth of a biological population of aerobic heterotrophs capable of storing orthophosphate in excess of their biological growth requirements. Exposing the bioculture of an activated sludge process to an anaerobic-aerobic sequence causes the proliferation of these microorganisms, known as phosphate-accumulating organisms (PAO), within the mixed liquor. Under anaerobic conditions, the PAO's convert readily available organic matter tocarbon compounds called poly-hydroxyalkanoates (PHA). The PAO's use energy generated through the breakdown of polyphosphate molecules to create PHA's. This breakdown results in the release of phosphorus. Under subsequent aerobic conditions, PAO's use thestored PHA's as energy to take up the phosphorus that was released in the anaerobic zone, as well as any additional phosphate present in the wastewater.

There are a number of biological nutrient removal treatment process configurations available. The configuration of the treatment process most appropriate for any system depends on the influent quality, required effluent quality, operator experience, existing treatment processes, and area available for expansion

Because of simplicity in operation, low oxygen requirement (low operating costs) and high quality of sludge produced, the three stages,widely used BNR processes, :Anaerobic, anoxic, Aerobic (known as A2O) configuration is adopted over other modifications in the present laboratory scale study. The main Objective of the study is to evaluate the nutrient (N &P) concentratios in the municipal wastewater of Mosul city, and to optimize the operating conditions for a

possible implementation of a Biological Nutrient Removal (BNR-A2O) process in the Wastewater Treatment Plant (WWTP) of Alkhadra (Mosul- Iraq).

LITERATURE REVIEW

In the past decade, a number of enhancedbiological nutrient removal BNR have been developed. They are a modified activated sludge process in which an initialanaerobic unit followed by anoxic and aerobic cycling of the activated sludge. Because of the complex biological transformation inthese processes, the biological removal mechanismsare not completely understood, hence the researches based on physical and mathematical models are continued to characterize these processes. Here we are introduce the most related studies to our work:

(Pai *et. al*. 2011) conducted a comparison between experimental and simulation values derived from a modified mathematical model based on the Activated SludgeModel No. 2d (ASM2d) established to describe the effluent qualitiesof A2O. The influentwastewater quality and quantity were fixed, the ratios of returnsludge and sludge retention time were 0.25 and 12 days, and the modelplant was operated at three different mixed liquid recycling ratios (MLRR, 0.5, 1.25, 2). When a steady state was reached, comparisonsbetween the measured values and predicted values were made for eachtest. A good consistency between the test values and simulation values was shown. According to our results, the biosorption effect of the soluble COD and the hydrolysis of the organic nitrogen in influentwastewater are the important qualities in activated sludge systems.Additionally, heterotrophic organisms might grow in the anaerobic tank.

(Shorbagyw. et.al , 2011) accomplish optimal sizing for a biological nutrient removal (BNR) system with an A2O BNR activated sludge process using activated sludge models (ASM) kinetic models. The paper includes a detailed description of model formulation, problem definition and discussion of optimal design in terms of capital (CAPEX) and operating (OPEX) cost estimates. The optimization problem is formulated and solved using typical cost factors and operating/design constraints applied to a typical illustrative system treating medium-strength wastewater. Results indicated that maintenance and sludge disposal expenditures represent more than 50% of the total annual cost and 80% of the annual running operating cost. Another major finding was that a primary clarifier is found to be cost ineffective in the A2O BNR process. Sensitivity of the optimal solutions and model performance to varying inflow conditions and to other effluent limits and model parameters will be discussed in another paper.

(Pai *et. al*., 2001) compared the consistency between simulation and observed values of different soluble components in A2O process to validate using an extended activated sludge model (or termed Tai Wan Extended Activated sludge model, TWEA1).. The success of modeling the two-stage nitrification/denitrification behaviors was resulted from some extended kinetic equations considered in TWEA1:(1) the contribution and processes of heterotrophs which used different carbon sources toreduce NO2 and NO3 under aerobic or anoxic conditions, (2) the contribution and processes ofphosphorus accumulating organism (PAO) which reduce NO2 and NO3 under aerobic or anoxiccondition, and (3) the contribution and two-stage nitrification processes of Ammonia Oxidizing Bacteria AOB and Nitrite Oxidizing bacteria NOB whichoxidized ammonia (NH4) and NO2 under aerobic condition. According to simulation, in anaerobictank, NO2 and NO3 did vary significantly. AOB and NOB decreased due to lysis, their concentrations were 19.0 and 10.6 mg L-1 and their net growth rates (Rg) were 2.4 and 1.8 mgL-1d-1, respectively. In anoxic tank, NO2 and NO3 decreased due to denitrification of PAO.AOB and NOB decreased due to lysis, their concentrations were 18.0 and 9.9 mgL-1and their Rgwere 2.5 and 1.8 mgL-1d-1, respectively. In aerobic tank, NO2 and NO3 increased due to aerobicgrowth of AOB and

NOB. AOB and NOB increased due to aerobic growth, their concentrationswere 20.2 and 11.1 mgL-1and their Rg were 10.7 and 1.2 mg L-1 d-1, respectively.

(Eberle K. *et. al*., 2006) presented the case study of the Triangle Wastewater Treatment Plant in Durham, North Carolina. The facility is achieving stellar performances with a stateoftheart, simultaneous biological nutrient removal treatment facility designed around the Kruger Modified A2O process. The treatment process is designed to produce an effluent at design flow conditions (12 MGD) with residual biological oxygen demand (BOD) of less than 5 mg/l and a total suspended solids (TSS) of less than 30 mg/l while simultaneously achieving a TN annual mass limit of less than 100,042 lbs/yr (equivalent to 2.75 mg/l at 12 MGD) and a TP annual mass limit of less than 10,224 lbs/yr (equivalent to 0.28 mg/l).

(Mayor L.R *et. al*.,2003)optimized the operating conditions for a possible implementationof a Biological Nutrient Removal (BNR) process in the Wastewater Treatment Plant (WWTP) ofCiudad Real (Spain). Several factors (hydraulic retention times, anaerobic nitrate concentration, sludge age and wastewater biodegradability) were tested using a pilot scale VIP (Virginia InitiativePlant) activated sludge process and domestic wastewater from the full scale plant. Hydraulicretention times used did not cause changes in N and P removal. P removal was adversely affectedby anaerobic NO_3 and improved with higher BOD5/COD ratios in wastewater. Influence of sludgeage was very low in P removal, but N removal was mainly affected by this factor. Final operatingconditions were selected taking into account their effects over one of both nutrients. COD and SSremoval were always successful. N removal was also easily reached and the main difficulty was Premoval. P sludge content was very low (2.5–4%) approximately and was also affected by the samefactors tested. The main factor to improve P removal was supposed to be the organic wastewatercomposition. Wastewater characteristics were modified by using different sources from the WWTP.Volatile fatty acids (VFA) addition to the wastewater by using supernatant of the anaerobic sludgedigesters seemed to be the best practical solution for a future BNR implementation in the WWTP.

(Boyle *et. al.,* 2009) studied the effect of internal recycle on the efficiency of A2O process. The removal in the anoxic/aerobic activated sludge reactors was sufficient to meet the summer resource consent standard. The recycle returned nitrate rich mixed liquor from the downstream aerobic zone back to the initial anoxic zone, thus potentially improving denitrification. A full scale trial showed that installation of the internal recycle on each RC would have satisfied the resource consent for total nitrogen in most cases over the three summer resource consent periods since the upgrade. However, further modifications of the internal recycle would be required to ensure that consent conditions were satisfied at all times and to improve the consistency of the results.

The study of (Jimenez, *et. al*., 2008) have dealt with the effect of the reactor configuration on this important kinetic parameter. Bench-scale and full-scale trials were devised to study the impact of the internal mixed liquor recycle (IMLR) on the nitrifier growth rate constant. The nitrifier growth rate constant for an existing activated sludge plant was determined at different operational conditions using the High F/M test and by process model calibration. Based on the results obtained during this investigation, a 15-percent decrease in μA, max was observed at IMLR of 4Q or higher. It is surmised that at high IMLRs, the reactor behavior shifts from a plug-flow configuration to a “ quasi” complete mixed configuration influencing either the species selection in activated sludge population or at least adaptation of specific species. These results have a tremendous impact on the design of activated sludge processes that incorporate IMLR for denitrification such as the Bardenpho, MLE, UCT and A2/O.

MATERIALS AND METHODS

Laboratory Bench Scale A2O Process

The activated sludge A2O process was developed in a Laboratory- bench scale plant, whichconsisted of tank divided into three consecutive compartments (anaerobic, anoxic and aerobic). Mixing and pH controllers were used in this tank inorder to ensure approximately constant conditions of the wastewater fed to the process.Aerobic compartment was equipped with air diffusers and mixers. Dissolved oxygen concentration wasmeasured in all compartments, and controlled in the aerobic ones. The air was fedwith an air compressor. Variable speed peristaltic pumps were used for activatedsludge internal recirculation between aerobic and anoxic compartments (IR) and settled sludgerecycle (RAS) to the reactor. An elevated tank with controlled static head is used for feeding the influent wastewater to the plant.A schematic flow diagram of the plant is shown in Figure 1.

Wastewater

The influent wastewater was taken from a point after the preliminary treatment of an existing Al-Khadra wastewater treatment plant. The biological population used in the process was developed from the former existing conventional activated sludge plant, which was transformed into a nutrient removal sludge

EXPERIMENTAL PROCEDURE

Different factors affecting Biological nutrient removal were tested. Each experiment consisted of continuous running of the bench scale plant under stationary condition using selected values for the variables under study. The laboratory scale was continuously operated for more than seven months with the temperature controlled at 23±2.The effective volumes of anaerobic, anoxic, and oxide stage were 4, 4, and 8 L respectively. The SRT was controlled in the range of (10-12days) by the amounts of sludge wasted from the aeration tank. The dissolved oxygen (DO) and pHwere controlled in the aerobic tank. To ensure aerobic conditions in the aerobic compartment the dissolved oxygen is maintained >2 mg/L during all experiments (Metcalf and Eddy, 2003). The mixed liquor suspended solids in aeration compartment was (1500-2000 mg/L) at steady state conditions.The variables under study were, the internal cycle ratio (IR), which were varied from (0% to 400%), Returned activated sludge ratio (RAS) which were varied from (15% to 100%), .The ratio between hydraulic retention times (HRT) in the different compartments A:A:O is maintain constant 1hr:1hr:4hr according to recommendation of (Mayor, 2004). Wastewater influent and settled effluent characteristics were daily measured. All analysis were performed using Standard Methods (APHA/AWWA/WEF, 1995).

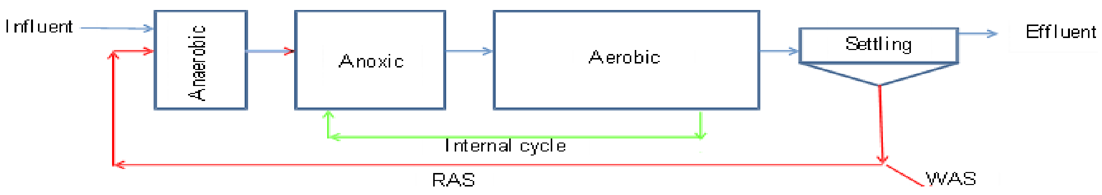

Figure 1: Schematic of Laboratory Bench Scale

RESULTS AND DISCUSSIONS

Table 1 lists the major components of theraw wastewater under study. It is taken from the existing Al-Khadra wastewater treatment plan.The analysis shows that both nitrogen and phosphorous should be reduced in order to meet the Iraqi standards.

According to the stoichiometry of nitrification de nitrification reaction the theoreticalamount of alkalinity needed to accomplish the process can be calculated from the following mas balance equation:

Alkalinity needed = Alkalinity to adjust pH + Alkalinity removed by nitrification – Alkalinity produced by denitrification

Alk. Needed = 70 + 7.14 $N\text{-}NH_4$ - 3.57N-NO3

Since our calculation is based on the weight of nitrogen in itscompounds and assuming a complete oxidation of ammonia in the aerobic zone and complete reduction of nitrate in the anoxic zone, the equation can be written as follows;

Alk. Needed = 70 + 3.57 $N\text{-}NH_4$

Alk. Needed= 70 +3.57 x 30= 177mg/L

Since the alkalinity in the waste water is 185 mg/L , there is no need for additional alkalinity.

Table 1: The Major Characteristics of Wastewater under Study

No.	Item	Unit	Concentration
1	Temp.	^0C	21-25
2	pH	--	7-7.9
3	COD	mg/L	180-280
4	Suspended solid (TSS)	mg/L	78-124
5	Total nitrogen (TN)	mg/L	25-30
6	Total phosphorus (TP)	mg/L	5-9
7	Alkalinity as $CaCO_3$	mg/L	185

In order to meet the desired nitrogen removal, several internal cycle ratio (IR) at different returned activated sludge ratios are examined as shown in the figures 2.

It is seen that without internal cycle (IR=0) there is no effect on the final effluent concentration with respect to total Nitrogen (TN). Under these conditions, the experiments shows that the predominant species of nitrogen compound in the effluent was nitrate (NO_3). According to the results obtained, The concentration of total nitrogen in the ultimate effluent decreases as the value of (IR) increases. This is agreed with the fact that nitrate rich mixed liquor from aeration zone combines with the substrate rich influent which sustain an optimal condition for the growth of denitrification heterotrophs which use nitrate as electron acceptor. Thus, it is familiar with those results obtained by (Metcalf and eddy, 2003) which pronounce that: IR ratios 200 -300% may be applied to meet the standards of 10 mg/L TN or less.

Referring to the same figures, The is no significant influence of returned activated sludge ratio (RAS) on the total nitrogen removal.

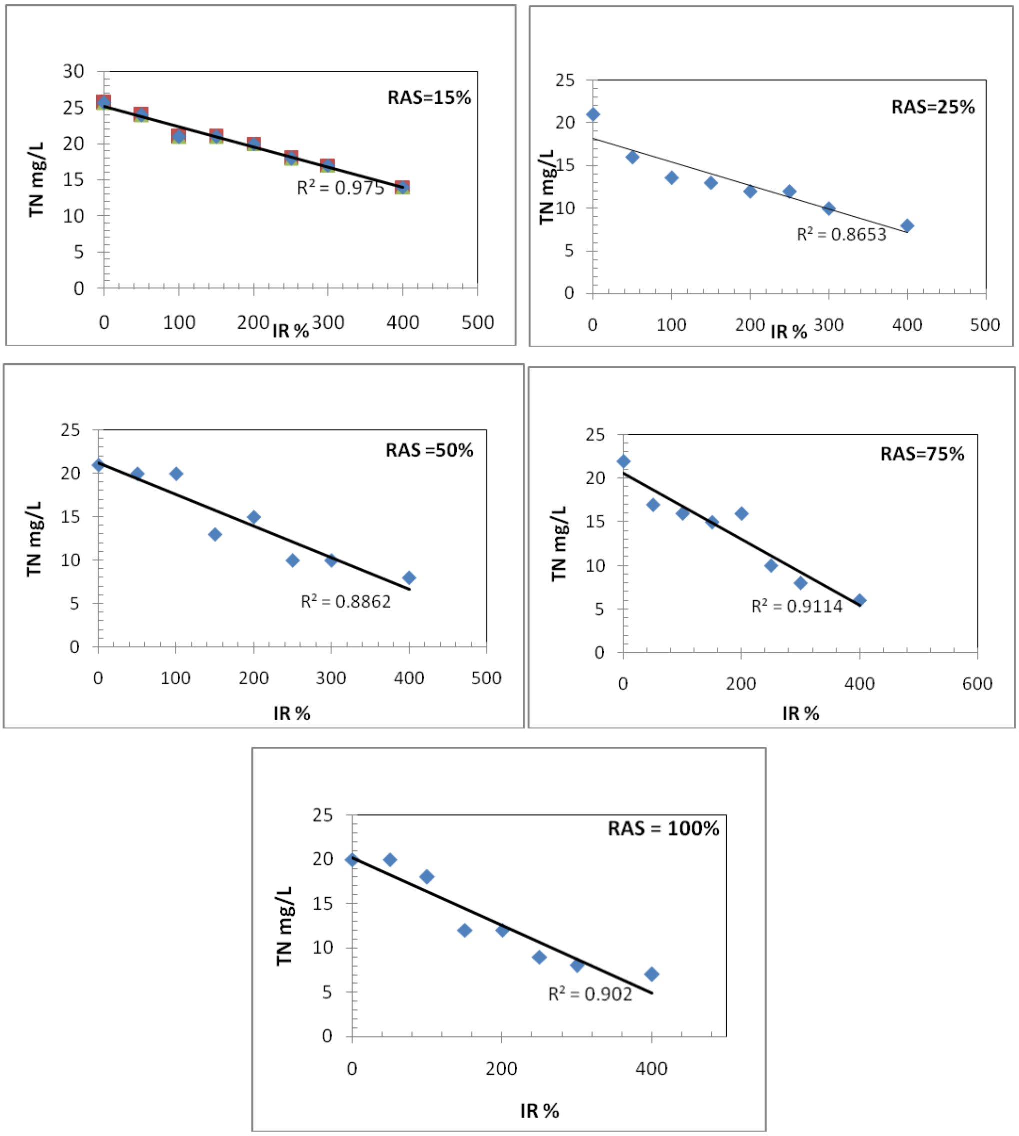

Figure 2: The Influence of Internal Cycle Ratio on the Total Nitrogen Removal

From an economical point of view, there is no benefit to use IR more than 200%, so that, the further study regarding biological phosphorous removal was done employing this IR upper limit. For this reason, the further experimentsaiming at biological phosphorous removal are conducted within a ratio of COD/P recommended by (Grady *et al*., 1999) as shown in the figure 3. The results revealed that at high percentages of RAS the biological phosphorous removal is less efficient, Since at High RAS (Long Solid retention time) the biological bacteria are in endogenous phase, which will deplete more of their intra- cellar storage product, so less efficient acetate uptake and polyhydroxybutyrate (PHB) storage will occurs in the anaerobic zone, which making the BPR less efficient (Stephens and Stensel, 1998). Moreover, at all examined RAS ratio, the Iraqi standard was achieved (Table 2)

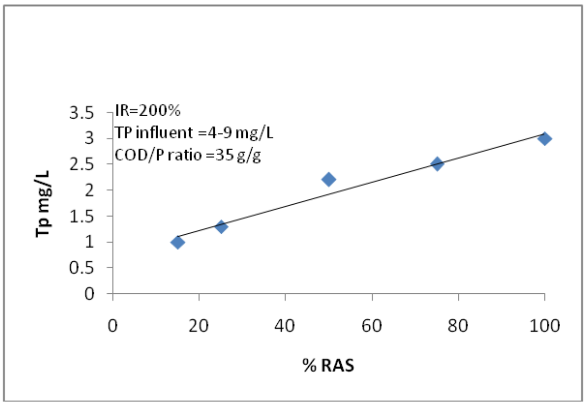

Figure 3: The Influence of Return Activated Sludge Ratio on the Total Phosphorus Removal

Table 2: Iraqi Regulation for Discharge of Sewage Effluent to Rivers (Ministry of Environment, 1967)

No.	Characteristics	Value
1	BOD_5 (mg/l)	40
2	COD (mg/l)	100
3	TSS (mg/l)	60
4	SO_4 (mg/l)	400
5	PO_4-P	3
6	NO_3-N (mg/l)	11.2
7	Cl^{-1} (mg/l)	600
8	pH	6-9.5
9	H_2S (mg/l)	3

SUMMARY AND CONCLUSIONS

- With respect to nutrient content, The raw wastewater under study, taken from the existing Al-Khadra wastewater treatment plant – Mosul city is not conform to Iraqi standards.
- The alkalinity content in the raw waste water under study is adequateto maintain the process of biological nutrient removal.
- The results revealed that at high percentages of RAS the biological phosphorous removal is less efficient.
- The total nitrogen removal is slightly affected by RAS ratio.
- To meet Iraqi standard with respect to nutrient (N, P), organic (COD) and solid (TSS) contents , employing A2O scheme, The optimum internal cycle ratio IR obtained from the study is(200%), While the significant range of Returned activated sludge recirculation ratio (RAS)is within 20-40%.

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